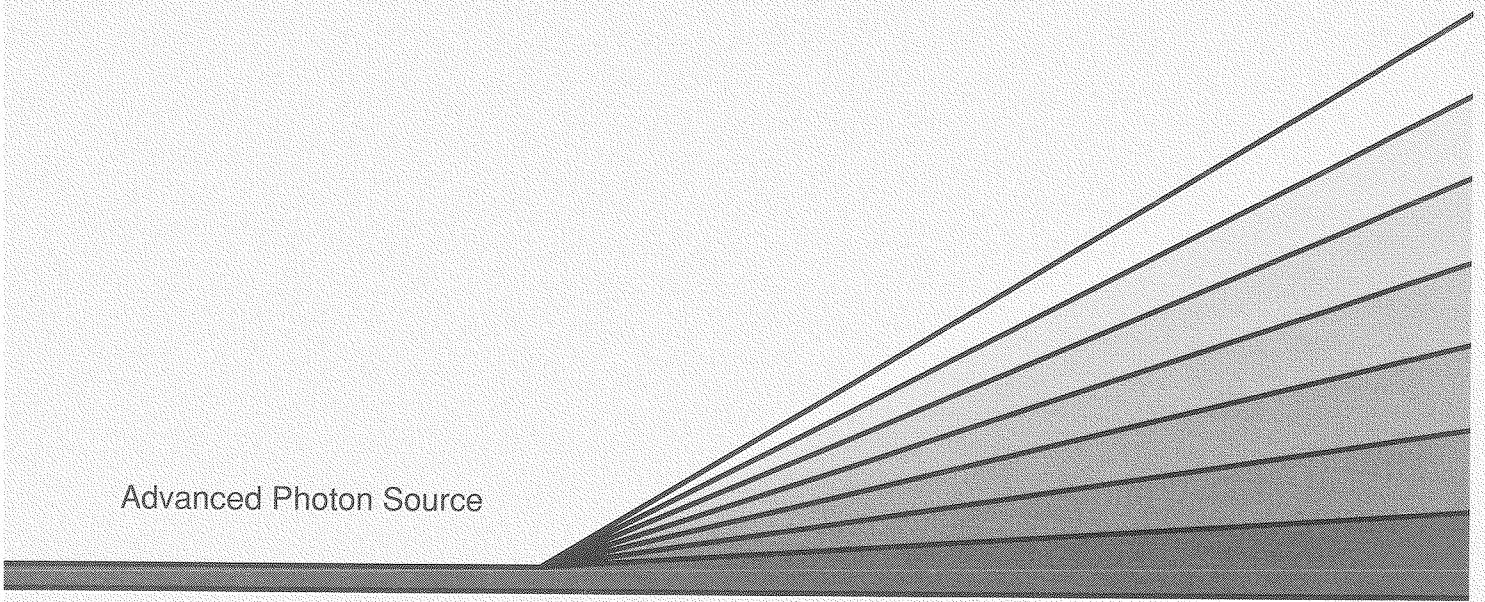
ANL/APS/TB-6

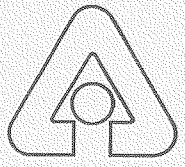
APS X-ray Optics Fabrication and Characterization Facility

by Steve Davey

February 1993



Advanced Photon Source



Argonne National Laboratory, Argonne, Illinois 60439
operated by The University of Chicago
for the United States Department of Energy under Contract W-31-109-Eng-38

Reproduced from the best available copy.

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
Prices available from (615) 576-8401

Available to the public from the
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Distribution Category: Atomic,
Molecular, and Chemical Physics
(UC-411)

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

ANL/APS/TB-6

APS X-ray Optics Fabrication and Characterization Facility

by Steve Davey

Experimental Facilities Division
Advanced Photon Source

February 1993

work sponsored by
U.S. DEPARTMENT OF ENERGY
Office of Energy Research

APS X-ray Optics Fabrication and Characterization Facility

The APS is in the process of assembling an X-ray Optics Fabrication and Characterization Facility. This report will describe its current (as of February 1993) design. The role of this facility is threefold:

(1) to develop fabrication techniques (mirror coating, multilayer fabrication, single crystal cutting and polishing, etc.) for new and/or improved x-ray optical components for use at the APS,

(2) to provide the capability for x-ray characterization of both single optical components (crystals, multilayers, zone plates, etc.) and complete systems (monochromators, crystal benders, etc.), and

(3) to provide the capability to measure surface figure and finish of components (mirrors, etc.).

Surveys of the APS Collaborative Access Teams (CATs) were conducted in 1992 that asked for specifications of expected optical needs. While not all of the optical needs of the CATs can be accommodated, these surveys provided guidance in how the APS might best fulfill the needs of the CATs. This facility will best serve the user community by providing for standard x-ray optical needs (e.g., on site x-ray diffractometers for orientation, etc.) and providing for some of the special optical needs of the APS user community (e.g., a mirror coating system for optics up to 1.5 m long). This facility will be operated by the staff of the APS and will compliment more standard optical shop facilities, such as the Argonne National Laboratory optics shop.

The surface metrology laboratory and the deposition system will be located in clean rooms in the APS Experimental Hall. The Experimental Hall floor will provide a mechanically stable environment for the labs. Figure 1 is the proposed layout of the deposition and the surface metrology labs.

The APS X-ray Optics Fabrication and Characterization Facility will be composed of the following:

1) A deposition system for single metal coatings for mirrors and synthetic mutilayer coatings

2) A surface metrology laboratory equipped with:
   - a figure interferometer
   - a surface profiler interferometer
   - a Long Trace Profilometer (LTP) or other large figure device

3) Single crystal optics fabrication facilities equipped with:
    a precision diamond slicing machine
    a lapper-polisher

4) X-ray characterization facilities equipped with:
    sealed tube x-ray generators
    diffraction equipment:
        double crystal goniometer
        triple axis diffractometer
        back Laue camera
        single axis goniometer for precision crystal orientation

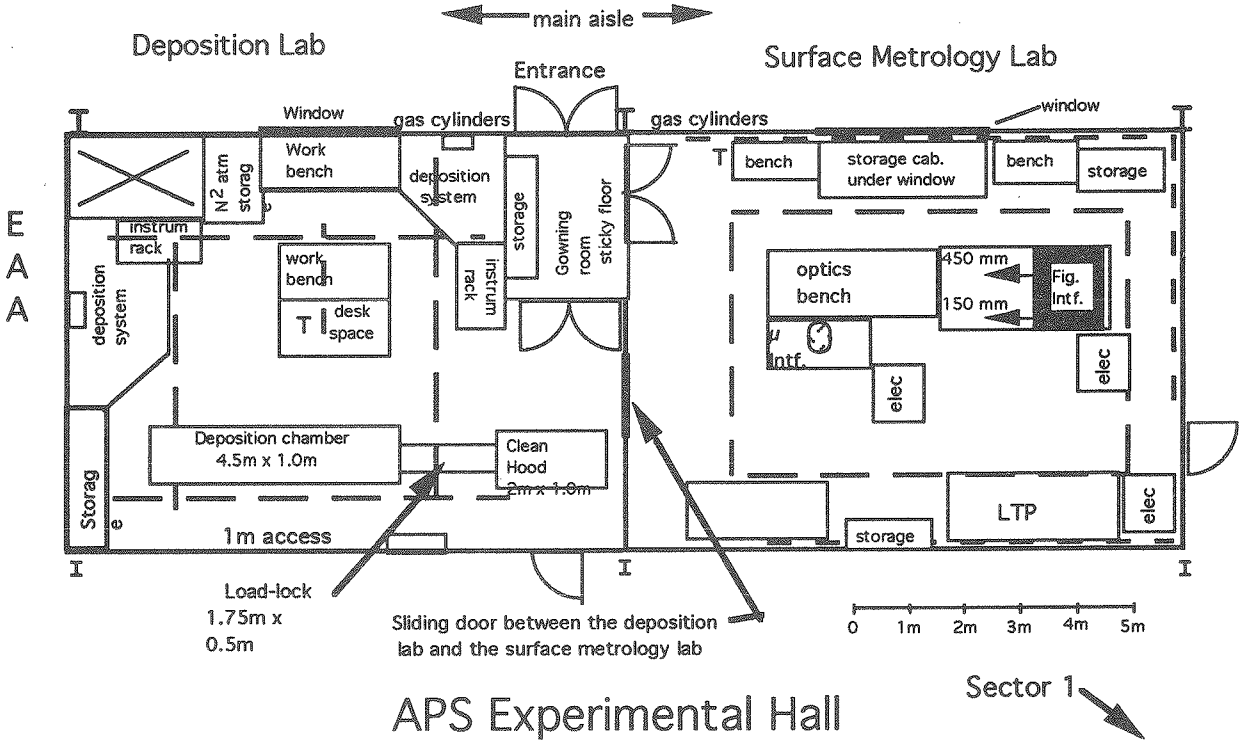


Figure 1 Proposed Deposition Lab and Surface Metrology Lab Layout. These labs are located in the Experimental Hall of the APS between Sector 1, the main aisle, and the Early Assembly Area (EAA).

Deposition Facility

A deposition facility will be constructed in a clean room on the experimental floor adjoining the surface metrology laboratory, refer to Fig. 1. This will provide a clean vibration-free environment for the coating chamber for single element metal coatings as well as synthetic multilayer coatings. A class 10,000 clean room or similar environment is planned. Based upon the results of a 1992 survey of the CATs' mirror expected requirements, most of the expected needs of the CATs could be accommodated with coating chambers that handle substrates that are:

1500 mm long x 150 mm wide x 125 mm thick for single element metal coatings and

500 mm long x 50 mm wide x 125 mm thick for multilayer coatings.

The materials for single element coatings include nickel, rhodium, gold, and platinum.

The design of the deposition laboratory will be completed by the spring of 1993 and constructed by early 1994.

Surface Metrology Laboratory

The surface metrology laboratory will be used to characterize the figure and the finish of x-ray optics. This laboratory will have the facilities to measure surface features with lateral (in the surface) resolution from less than a micron to lengths greater than a meter and with a vertical (normal to the surface) resolution as small as an Angstrom. It is currently planned to cover this entire range with three non-contact instruments, a surface profiling interferometer, a figure interferometer, and a long trace profiler. Each of these instruments is described in detail below.

Surface Profiler

A surface profiler is an instrument that will measure the 3D microscopic topography (finish) of optical surfaces. Vertical resolution of less than 1 nm is obtained using phase shifting interferometry. When operated with a low power objective, the field of view can be as wide as a few mm^2, and, with a high power objective, submicron lateral resolution is obtained. Typically, an interferogram will contain more than 60,000 data points and will be analyzed in a few seconds time.

The profiler will be used in the surface metrology laboratory to characterize both diffraction crystals and reflecting mirrors. These optics can be quite large and heavy. A typical mirror may be larger than

1.5 m x 100 mm x 100 mm and made of copper alloy. In order to accommodate such optics, the phase shifting hardware must be located in the microscope head and cannot be located in the support stage.

The surface profiler delivery is needed early in 1993 so that the finish of cut and polished x-ray optical components can be measured. This information will provide feedback for developing the crystal polishing techniques.

Preliminary APS Surface Profiler Description (2/93):

Phase shifting figure interferometer, optics and computer

Phase Shifting Optics

Mirau objectives X2.5 and X100

Field of View	>2.5 mm x 2.5 mm minimum
Vertical Resolution	<0.05 nm for all magnifications
Lateral Resolution	<0.5 μm
Repeatability	<0.2 nm rms difference of 2 measurement <0.05 nm rms 16 averages w/ null < 0.1 nm rms 16 averages w/ 5 fringes rms for 2 sigma of 100 sets of measurements each set is the average of 16 profile measurements
Reproducibility	sigma of 20 measurements will be less than 0.15Å, each measurement consists of 4 intensity averages with the instrument refocused between each measurement

Microscope column detachable from base for optical table mounting

Computer	HP 382/16+2 workstation or equivalent DOS floppy disk data transfer for compatibility with DOS PC Interferometer operation and analysis software

Accessories:

Precision Reference Standard
Vibration Isolation Optical Table (large enough to handle the profiler and the large optics) (4' x 8')
Optical Table Mounting Plate to replace standard profiler base

Additional desirable features:

Vertical steps >2μm
Turret-mounted objectives
Parfocal objectives
Turret less than or equal to 3" dia.
Objective working distances are maximized

Figure Interferometer

A figure interferometer characterizes the shape (figure) of optical surfaces and will be used to measure both diffraction crystals and reflecting mirrors. The APS digital phase-shifting figure interferometer was delivered in January 1993, and its specifications are provided in Appendix 1.

The figure interferometer will overlap the resolution and length scales probed by the surface profiler and a long trace profiler. The APS figure interferometer has a 6-inch clear aperture and has a 6:1 continuous zoom. The digitization resolution of 256 x 240 elements yields a lateral resolution of a fraction of a mm. A second port is available on which beam expander optics can be installed.

The phase shifter in this laser interferometer changes the relative optical path length of beams reflected from the test piece and an internal reference. The surface topography of the test piece is determined by calculating the optical path difference between the two beams. The data can then be plotted or analyzed for a variety of optical characteristics. The computer platform makes the measurements on a timely basis. Data acquisition and display take a few seconds.

Figure Interferometer Description

Phase Shifting Figure Interferometer, Optics and Computer

Phase Shifting Optics

Aperture	150 mm (6-inch aperture) [with the flexibility for larger aperture (e.g., 450 mm)]
Accuracy	better than λ/100 peak-valley (P-V) at λ=632.8 nm Value for accuracy reflects the overall system accuracy for absolute testing. System accuracy for relative testing is dependent on the quality of the reference optic.
Precision	better than λ/1300 rms (6-inch aperture) Instrument precision is the residual rms error that

reflects the difference of two consecutive measurements, each consisting of an average of 16 sets of data. The specification is derived from a sample of 100 measurements and represents the mean value plus 2 σ (98% confidence).

Repeatability	better than λ/ 1000 P-V (6-inch aperture) better than λ/ 8000 rms (6-inch aperture) Repeatability of the quoted statistic for 100 measurements, in which each sample consists of an average of 16 sets of data. The specifications are for the 2 σ (95%) repeatability of the data. P-V calculated over 97% clear aperture, rms calculated over 100% clear aperture.
Maximum Slope	better than 60 fringes
Zoom Range	6 X
Computer	IBM compatible DOS 486 PC platform processor

Accessories:

6" diameter transmission flat λ/20
attenuation filter
sample mount, 3 translations and 2 rotations
composed of a base support with x-y-z translation, a tip tilt adapter and a self centering three jaw chuck.
shelf mount that can be used in place of the three jaw chuck. The mounts described in these last two items are intended for use with smaller optics (e.g., monochromator crystals)

Long Trace Profiler

The APS is planning to procure a Long Trace Profilometer (LTP) which is available from Continental Optical Corporation or other measurement device that will characterize optical figures over lengths of at least 1 m. The desired large figure device shall be able to measure surfaces up to 1 - 2 m long with a lateral resolution on the order of 1 mm. For a slope-measuring device, such as the LTP, an accuracy of less than 2 μrad will be expected.

Single Crystal Optics Fabrication

The single crystal optics fabrication laboratory will be equipped with a precision slicing machine and a lapper-polisher. The three-axis CNC slicer specified in Appendix 2 has been installed at the APS for machining Si and

Ge crystals. The lapper-polisher described in Appendix 3 is being installed at the APS. Note that it can handle samples up to 10" x 3" without compromising flatness.

X-ray Characterization Facility

The x-ray laboratories will be equipped with the following diffraction instruments:

Double crystal goniometer for measuring rocking curves
Triple axis, four circle diffractometer
Back Laue camera for rough crystal orientation
Single axis goniometer for precision crystal orientation
Crystal mounts to transfer oriented crystals to the slicer.

This standard diffraction instruments will not be described in detail here.

Appendix 1
WYKO - 6000PC Figure Interferometer Specifications

(Specifications from *The WYKO 6000PC Interferometer*)

WYKO 6000PC Specifications

System Performance

Calibrated accuracy:	Less than λ/100 rms
System accuracy:	Dependent on reference optic quality
Repeatability of p-v:	Less than λ/100 2σ deviation of 100 measurements, each averaging four sets of data
Repeatability of rms:	Less than λ/1000 2σ deviation of 100 measurements, each averaging four sets of data
Measurement resolution:	λ/1024
Data acquisition time:	Less than 167 ms
Measurement-to-measurement repeatability:	λ/500 or better Max. rms deviation between any two consecutive measurements

Interferometer

Optical configuration:	Fizeau interferometer
Test beam diameter:	152.4 mm (6 in.)
Source:	Actively stabilized HeNe laser
Frequency stability:	±0.5 MHz/min., ±2 MHz/hour
Pupil imagining:	Continuous 6:1 zoom
Alignment FOV:	±2 degrees
Fringe viewing:	TV monitor
Active pixels:	745 x 488
Digitized resolution:	256 x 240
Test beam height:	133.4 mm ± 2.5 mm

Appendix 2
Meyer Burger - Slicing Machine Specifications

The slicing machine TS 121 is especially designed for the automatic slicing of hard and brittle materials (e.g. optical glass, ceramic materials, quartz etc.) by means of diamond tools.

Some special features

- Non-corroding protection of the working area
- Slide ways and limit switches outside the working area
- Slide drives with DC-servomotors
- Positioning of the longitudinal slide with incremental rotary encoder
- Positioning of the cross and vertical slide with incremental linear transducers
- CNC-continuous-path-control for 3 axes and CRT-screen in the control cabinet next to the machine

Technical data

Slicing blade:	External diameter	250–400 mm
	Bore	32 mm
	Cutting speeds in range from	10–75 m/s
	Slicing blade flanges	dia. 100, 140 or 200 mm
Tool spindle:	14 fixed spindle speeds in range from	800–3550 rpm
	Spindle diameter	32 mm
	Motor rating and speed of the three-phase AC-motor	4 kW / 1500 rpm
Longitudinal slide:	Maximum travel path	500 mm
(X-axis)	Cutting feed speed programmable from	5–2000 mm/min
	Longitudinal travel paths programmable from	0.001–500 mm
	Rapid traverse	2000 mm/min
	Digital display of feed speed in	mm/min
	Digital display of slide position	0.001 mm
Cross slide:	Maximum travel path	320 mm
(Y-axis)	Feed speed programmable from	5–2000 mm/min
	Feed step lenght programmable from	0.001–320 mm
	Rapid traverse	2000 mm/min
	Digital display of feed speed in	mm/min
	Digital display of slide position	0.001 mm
Vertical slide:	Maximum travel path	160 mm
(Z-axis)	Feed speed programmable from	5–2000 mm/min
	Vertical travel paths programmable from	0.001–160 mm
	Rapid traverse	2000 mm/min
	Digital display of feed speed in	mm/min
	Digital display of slide position	0.001 mm
Worktable:	Rotary table	dia. 375 mm
(Special accessory)	Adjustment with handwheel or DC-servomotor (C-axis)	
	Rotary table turns	360 °
	With handwheel: angle adjust to 1' =	0.017 °
	With servomotor: angle values programmable in 0.001° =	3.6 ''
	Quick adjustment (rapid traverse) with servomotor	6 rpm
	Distance spindle axis – rotary table	217–377 mm
Dimensions:	Machine	1300×1380×2230 mm
(W×D×H)	Control cabinet	600×1000×2000 mm
Weight:	Machine	1700 kg
	Control cabinet	300 kg

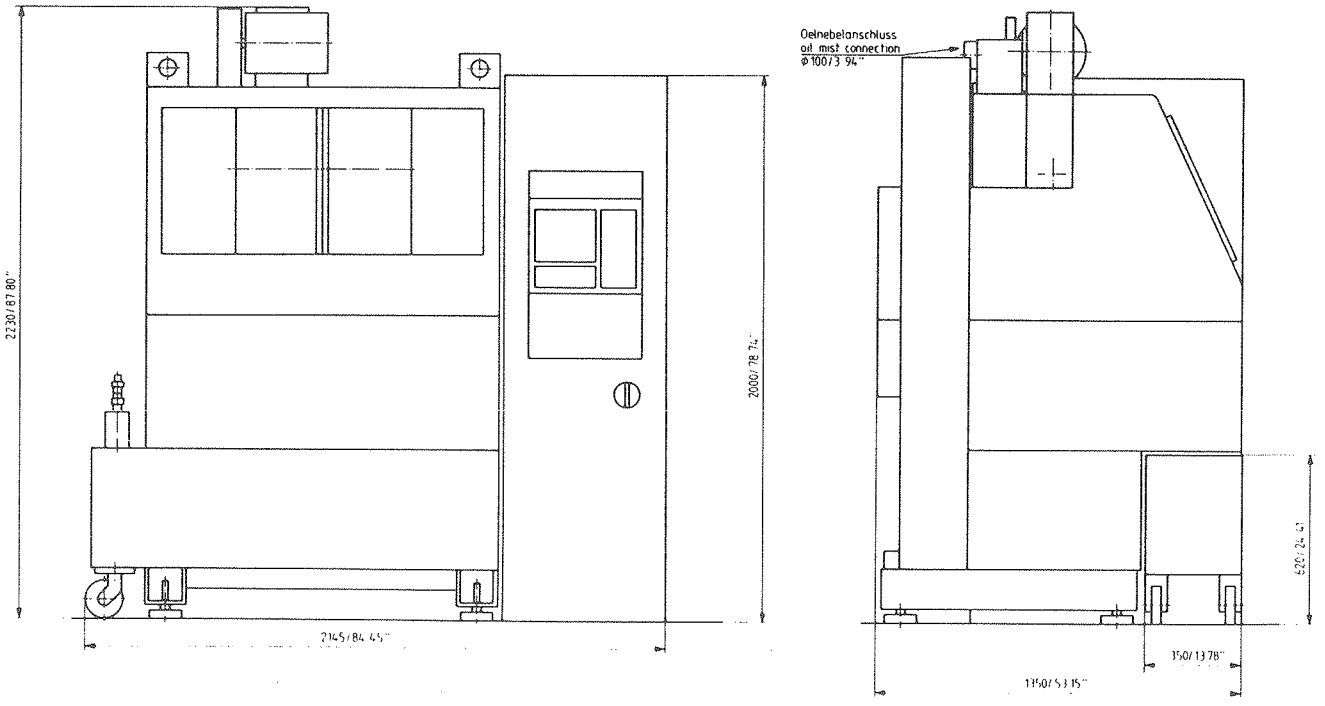
Standard equipment for slicing machine TS 121

2 Lever rods for transporting machine
1 Spindle dia. 32 mm to hold slicing blade
2 Spacers dia. 55 mm and groove nut
1 Pair flanges dia. 100, 140 and 200 mm
1 Spindle main bearing with or without driving notch
1 Fixed spindle speed in range from 800 to 3550 rpm
1 Motor pulley, diameter depending on desired rpm
1 Spindle pulley, diameter depending on desired rpm
Spindle speeds possible with spindle motor 4 kW, 1500 rpm (50 Hz)
800, 900, 1000, 1120, 1250, 1400, 1600, 1800, 2000, 2240, 2500, 2800, 3150 and 3550 rpm
1 Taper reduction for counter bearing and 2 draw-in screws for using the spindles of slicing machines TS 3, TS 33, TS 4 and the quartz cutting machine QS 3
2 Movable coolant supply pipes with nozzles
1 Set operating keys
1 Operating instructions with wiring diagram, diagrams and equipment list

Additional equipment necessary to operate the machine

Diamond slicing blade
Workpiece-worktable (rotary table or magnetic chuck)
Work holder plate 300×250×12 mm
Cement, e.g. A46 for fixing the workpieces
Support plate (made of e.g. glass, ceramic etc.) for cementing the workpieces
Coolant, e.g. Mill-Kut 12-CO
Coolant and grinding agent concentrate, e.g. OEST Meba SKNF
Dressing stone for slicing blade, e.g. Abrafract BFR 200

Machine dimensions



Appendix 3
Engis - HYPREZ Lapper-Polisher Specifications

ENGIS CORPORATION

105 W. Hintz Road
Wheeling, Illinois 60090 USA

TELEPHONE: (708) 808-9400
FAX: 708-808-9430
CABLES: ENGISCO
WHEELING, IL (U.S.A.)

Item	Description
1	HYPREZ LAPPING SYSTEM MODEL 28LMPV (PNEUMATIC PRESSURE SYSTEM WITH VARIABLE SPEED)

Standard features:

- Microprocessor Base Touch Control Panel with Large, Easy-to-Read L.E.D. Displays Mounted to a Movable Pendant for Convenient Access at Each Work Station
- Electronic Variable Speed Drive (Inverter) Adjustable from 0-100 RPM, 5HP, 230VAC
- 3 Ring Arms - Roller Yoke Type
- Each Pneumatic Station has a Single Lever Control for Both Inboard and Outboard Adjustments
- The Complete Pneumatic Structure Can Be Swung to the Side of Machine for Easy Access to Lap Plate for Removal or Cleaning
- 3 H.P. - 3 Phase Drive (Soft Start Drive)
- Abrasive Slurry Pump System
- Separate Oversize Tapered Roller Bearing
- Spindle Driven by a Quiet Antifriction Gearbox and Motor Combination via a High Torque Belt and Pulley System
- Large Bore Cylinders with Double Pistons and Oversize Piston Rods for Supporting Greater Lapping Pressures and Frictional Drag
- Air Filter Lubricator
- 35" Work Height for Easy Loading and Unloading
- 48" Diameter Fully Adjustable Parts Table
- 3 Natural Iron Conditioning Rings (12" I.D.)
- Flatness Gauge for Plate
- NEMA 12 Wiring
- 208V, 3 Phase Electrics
- 500 lbs. Maximum Load Delivered per Cylinder

Dimensions: 58"L x 48"W x 74"H

Shipping Weight: 3,000 lbs. approx.

Delivery: 5-7 weeks from receipt of P.O.